Fermi National Accelerator Laboratory

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The Pierre Auger Observatory

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Abstract. The Pierre Auger Observatory is an international collaboration for the detailed study of the highest energy cosmic rays. The Observatory will operate at two similar sites, one in the northern hemisphere and one in the southern hemisphere. Important contributors to this effort are institutions in latin american countries. The Observatory is designed to collect a statistically significant data set of events with energies greater than 10^{19} eV and with equal exposures for the northern and southern skies.

INTRODUCTION

The Pierre Auger Observatory (PAO) is an international collaboration of over 200 astro-physicists and elementary particle physicists from 18 different countries, representing more than 20 institutions. It has strong participation from both the southern and northern hemispheres and from all continents [1].

The concept of PAO was developed at workshops in Paris 1992, Adelaide 1993, Tokyo 1993 and Fermilab 1995. Professors Jim Cronin and Alan Watson are the spokespersons. A design report has been written, a new version of which will be available February 1997. During an organizational meeting in Paris, November 1995, the southern site location was selected in Argentina. At the first collaboration meeting in San Rafel, Argentina, September 1996, the northern site was selected to be in the USA.

Since the first evidence of their existence, in balloon flights by V. Hess in 1912, cosmic rays (CR) have been extensively studied. In 1938 Pierre Auger observed for the first time extensive air showers (EAS) by observing CR coincidences with detectors separated from each other. Estimates of the energies involved in the first EAS observed was already in excess of 10^{15} eV.

Enrico Fermi proposed in 1949 a possible method of accelerating particles that could explained the presence of such extremely high energies. In effect, the CR energy spectrum has now been measured over more than 10 orders of magnitude in energy.

COSMIC RAY FLUXES

The measured flux of CR falls with a power of the energy of the order of 2.5 to 3. For each decade of increasing energy, the flux decreases three orders of magnitude. This logarithmic dependence of the flux with energy is predicted by different acceleration models.

The slope of the flux versus energy shows some structure near 10^{16} eV and also around 10^{19} eV, the so called "knee" and "ankle" features. No "toe" has been found [2]. At 10^{20} eV the measured flux is as low as approximately one event per Km^2 per steradian per century per decade of energy. The combined design acceptance for both sites of the the PAO is 14,000 Km^2 sr, yielding an estimated data collection rate of the order of 140 events per year, at the highest observed energies.

Only about 10 events with energies around 10^{20} eV have been detected to date. In 1991, at the Fly's Eye detector (Utah, USA) an event of 3.2 x 10^{20} eV was detected; an energy of 50 Joules! This is the highest energy event ever recorded. In 1993, at the Agasa detector (Akeno, Japan) an event of 2.0 x 10^{20} eV was detected, 10^8 times the energy of protons accelerated in the highest energy ground based accelerator, the Fermilab Tevatron.

The measurement of the 2.7 °K Microwave Background Radiation (MBR), by A. Penzias and R. Wilson in 1966, had an important consequence; the realization that CR interactions with the MBR will cause an energy loss mechanism. Nucleons above a certain energy threshold produce pions in collisions with photons. This process continues until the energy falls below threshold. For long distances, particles originally with an energy distribution above threshold, will continue to propagate with the "same" energy just below threshold. Therefore, for CR of energies in excess of 10^{19} eV, the observed energy at an earth-based detector will depend on the distance traversed by the primary particle between the source and the detector. The energy spectrum is then expected to be "limited" by this threshold effect to around 10^{20} eV for particles travelling intergalactic distances. This is the so called GZK cut-off, from the calculations of K. Greisen, V. Kuzmin and G. Zatsepin. These calculations have been recently updated by M. T. Dova, L. Anchordoqui, L. Epele and J. Swain of the Auger Collaboration. The energy loss takes place within distances of the order of 100 Mpc. For these distances, depending on the actual distribution of primary sources and their flux, an enhancement could appear in the energy spectrum between 10^{19} and 10^{20} eV due to a lower detected energy than the original at the source. Particles detected with energies above the enhancement must originate within 20 or 30 Mpc from the detector.

Primary high energy CR nuclei undergo a loss of nucleons through the intergalactic space of about 4 nucleons per Mpc. Therefore, for distances longer than 50 Mpc, only nucleons should be observed. The Fly's Eye detector has evidence for a change of composition of CR with energy, mainly nuclei at lower energies changing to nucleons at higher ones.

The transverse momentum exchange in the interaction with the MBR is expected to be very low, therefore the CR direction is not significantly affected. Observation of an enhancement in the energy spectrum could be used for separating the data in "near" and "far" samples when tracing back the arrival directions. The apparent arrival direction of the observed CR may not point back to the source due to the possible magnetic fields in their trajectory. For punctual sources emitting at different energies, and given sufficient statistics, one could observe a distribution of arrival directions, converging to the source as the detected energy increases. The magnetic field in our galaxy of the order of 2 to 3 μ gauss over some kpc, will cause only a small deflection for CR of the order of 10^{20} eV, so that they could not have originated from the center of our galaxy, and therefore are most likely of extra-galactic origin.

The large increase in data collection to be provided by the Auger Observatory will allow a detailed study of the energy spectrum, arrival directions and possible assymetries of CR near and above the GZK energy cut-off. This information could help to identify their source and acceleration mechanisms. Possible candidates are: powerful radio sources, Active Galactic Nuclei by shock acceleration, association with Gamma Ray Bursts, annihilation of topological defects, etc. No proposed mechanism can currently explain acceleration beyond 10^{20} eV. If the energy spectrum extends significantly beyond the GZK cut-off one may need to consider the possibility of some new astrophysics or particle physics phenomena.

THE PIERRE AUGER OBSERVATORY

An EAS develops when a high energy primary particle (e.g. a nucleon, a heavy ion, or a neutrino) collides with the atmosphere and produces a number of secondaries that interact further with the atmosphere, giving rise to succesive generation of particles. The details of the EAS depend on the type of primary particle and its energy. A typical 10^{19} eV proton shower when fully developed could contain as many as 10^{11} individual low energy particles, 90% gammas and 10% electrons of MeV energies and 1% muons with 1 GeV energies.

An EAS can be characterized by experimentally determining the position of shower maximum, X_{max}, its radial particle density distribution (e.g. at the ground), its arrival time and front shape and two angles defining its direction. Of equal importance is to determine the species of the primary particle, that can be infered by the muon content of the EAS and the time characteristics of its front.

The atmosphere is a good calorimeter with a vertical depth of approximately 1,000 gm cm^{-2}. Shower maximum for primary charged particles occurs at about a depth of 850 gm cm^{-2}, or 1500 meters above sea level. The atmospheric vertical thickness represents approximately 26 radiation lengths and 11 interaction lengths, sufficient for good calorimetric measurements. For horizontal showers the atmospheric depth is about 36 times thicker, becoming a good "beam dump". This mass is enough to open the possibilty of utilizing the PAO for the detection of neutrino induced horizontal EAS.

The PAO will consist of two detectors, one in each hemisphere, with a total acceptance of 14,000 Km^2 sr. Each site will occupy a surface of 3,000 Km^2 with an acceptance from the zenith down to $60°$. Each detector will combine two well developed CR calorimetric detection techniques, ground array (GA) detection and atmospheric fluorescence (FD) detection.

The GA samples the EAS at ground level with capabilities for the measurement of the radial particle density distribution, the timing characteristics of the shower front, and for distinguishing muons from electromagnetic components. Timing information gives the shower direction as well as contributes to the muon separation. Both southern and northern hemisphere sites are situated at 1400 m altitude, or very close to shower maximum. The ground level sampling is then done close to the peak of the shower development. The GA will have a 100% duty cycle and full sky coverage for anisotropy studies. Each site will consist of more than 1500 water Cherenkov detectors located 1.5 Km apart. Each detector will be circular, 10 m^2 of surface and 1.2 m high. It will be instrumented with 3 photomultipliers, 22 cm in diameter (or an equivalent total photocathode area), looking down into the water. The detectors will be arranged in an hexagon, or in a three fold symmetrical shape, of 3,000 Km^2 total area.

The FD measures the longitudinal development of the EAS by detecting the nitrogen fluorescence from charged particle excitation of the nitrogen atoms; it therefore tracks the longitudinal development of the EAS, giving the position of X_{max} and information on its direction by fitting the longitudinal distribution. Due to the requirement of a dark sky, the FD can only operate for about 10% of the total time. This fraction may be increased (to 20% ?) as techniques are developed for triggering the FD with the GA. Two proposed designs exist for the FD. They differ in the number of "eyes" or locations. More than one eye is required because of the attenuation length of the fluorescence light in the atmosphere, of the order of 17 Km. The minimum number is three "eyes", symmetrically placed within the GA surface area in its three fold symmetrical configuration. Each "eye" looks at the sky above the GA from 3° to 30° from the horizontal and 360° on the horizontal plane. Pixel sizes are 1.5° by 1.5 ° each. The alternative design is for 6 "eyes", one in each corner of the hexagon plus one "eye" in the center of the array. Both designs require the same total number of pixels, or individual photomultipliers.

Two sets of data will be available, the hybrid set with GA and FD information and the GA only data. Because of the following advantages, the hybrid data set is one of the important characteristics of the PAO,

- independent measurement techniques allow control of systematics
- FD and GA give a more reliable energy and measurements of angles
- FD calibrates the energy determination of the GA
- EAS front timing, core position and surface particle density improve the energy and angle determination for the FD
- the two techniques measure the primary mass in complementary ways

MEXICO AND THE PIERRE AUGER OBSERVATORY

The following Mexican institutions participate in the PAO:
CINVESTAV
Benemerita Universidad Autónoma de Puebla
Universidad Nacional Autónoma de Mexico
Universidad Michoacana de San Nicolas de Hidalgo
Universidad de Guadalajara
Universidad Autónoma de San Luis Potosí
Instituto Nacional de Astrofísica Óptica y Electrónica
Centro de Investigaciones en Materiales Avanzados

The Mexican Auger group is working on a variety of topics for the project. Front End Electronics using Switch Capacitors Array or Flash ADC is being developed at Puebla. Surface detector simulations are underway at CINVESTAV IPN and at Puebla. Water Cherenkov tank prototypes made of high density polyethylene and reflective TYVEK^{MR} material on the internal walls is being devloped jointly by Puebla and Michoacan. An Optical design has been proposed for the FD jointly by Puebla and INAOE.

COST AND SCHEDULE

The total cost for both PAO sites is estimated to be of the order of 100M $us. Of this, about 50M $us is expected to be the cost of the GA and about 30M $us the cost of the FD. The remainder of the estimated cost is for infrastructure, the central stations, site preparation, engineering costs, etc. To date no real breakdown of the sources of support exists. Expectations are for 25% of the support to come from each of the North American, South American, European and Asian continents. Most of the contributions are expected to be "in kind" with only a fraction of them required for a "common fund" for joint expenditures.

In parallel with the completion of the PAO design, most of 1997 will be dedicated to the submission of proposals to the funding agencies of each country by the collaborating institutions. During this year a number of scientific and design reviews are expected to take place. Expectations are for funding for the construction of PAO to start late in 1998. The collaboration has a 5 year construction and deployment plan. After the second year of construction is completed, PAO is expected to have the largest operating ground detector array in existence. As the PAO is completed it will continue to increase in size, to be more than double in size on the following 3 years. Early in the 21st century the Pierre Auger Observatory should have a catalogued hundreds of Cosmic Rays with energies in the 10^{20} eV range.

REFERENCES

1. Due to the limited space for further information and references please contact the author at "hojvat@fnal.gov".
2. The presence of a "toe" would indicated the end of the energy spectrum, Alvaro de Rujula, private comunication.